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An Evaluation of the Land Cover Classification Product *Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016* for Namibia

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ABSTRACT

Global information on land cover is a primary output of remote sensing applications due to its importance to global change sciences, but also to governments and international initiatives. Consequently, a variety of land cover datasets have been developed in the past. Today users can choose among different products with various spatial resolutions for applications on global as well as on regional scales. A new classification covering the African continent was released by the European Space Agency only recently. Thanks to its mapping approach of 20 m, the *Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016* constitutes a novelty among the freely available products. However, being only a prototype, it is still missing final validation. This study aimed at evaluating the classification for the extent of Namibia by quantitatively and qualitatively comparing it to a selection of four low- to medium-resolution land cover products. Within the framework of an accuracy assessment for four test sites, statistical parameters were calculated which served as indicators for assessing the classification quality. According to the analysis, the overall accuracy of the prototype land cover product is on a medium level attaining approximately 54%. The per class accuracy varies from 2% to 100% suggesting that some classes require considerable reworking whereas others need less improvement. However, compared to the reference datasets, the prototype classification already constitutes a major development in land cover mapping.

Keywords: Accuracy assessment; classification; European Space Agency; land cover; Namibia; Sentinel 2; spatial resolution; validation

INTRODUCTION

Global information on land cover (GLC) is of importance for environmental change studies but also for international initiatives engaging in e.g. land resource management. Since the development of the first land cover dataset in the 1980s, the number of products has constantly risen (DeFries *et al*. 1995, Matthews 1983, Olson *et al*. 1985, Wilson & Henderson-Sellers 1985). However, not only the quantity but also the quality has changed thanks to the availability of higher resolution sensors. The initially low spatial resolution of 1° has been gradually increased to 1 km (e.g. *DISCover*) (Loveland *et al*. 2000), 500 m (e.g. *MODIS/Terra & Aqua Combined Land Cover Type Global 500 m SIN Grid, MCD12Q1*) (Friedl & Sulla-Menashe 2018) and 300 m (e.g. *GlobCover*) (Arino *et al*. 2011). These spatial resolutions are still too low for most regional and local scale applications. The publication of the classification *GlobeLand30* with a 30 m mapping approach has therefore been of great importance to the mapping society (Chen *et al*. 2015). A further improvement is the 20 m medium-resolution land cover map *Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016* (*S2 LC Africa*) of the European Space Agency (ESA), which was released in September 2017 (Ramoino *et al*. 2018). Due to its exceptional spatial resolution, it currently takes a special position among the freely available land cover products for Africa. However, it is still a prototype that has not yet been validated on a regional scale. Up to the time of this research there was only one detailed study of the authors Lesiv *et al*. (2017) who had examined the product accuracy using two independent land cover datasets at 10 m resolutions developed within the Copernicus Global Land Services (CGLS). According to their estimates, overall accuracy of the prototype LC Africa map at 20 m was approximately 65%. Regions were highlighted where the spatial distribution of specific land cover classes such as shrubs, crops and trees should be improved before the map can be used as input for research questions, e.g. conservation of biodiversity, crop monitoring and climate modelling. These regions also include the central and north western areas of Namibia which are characterised by a more inhomogeneous land cover and higher overestimations of shrub, grass and croplands. The main aim of the study was to comply with the request of the ESA to evaluate the quality of the *S2 LC Africa* product and provide further user feedback. Four freely available low- to medium-resolution land cover datasets served as reference.

METHODS

Study Area

Namibia is characterised through clearly definable landscape units with a multitude of different forms and shapes (Hüser *et al*. 2001). Along with the gradually changing climatic conditions, they result in a varying plant density and diversity (Mendelsohn *et al*. 2009). This makes the country interesting for land cover analysis. Furthermore, its rainfall gradient from the northeast to the coast in the west allowed the choice of four highly heterogeneous test sites with a size of 50 km x 50 km (Figure 1). These not only capture hydric differences, but also topographic variability. Whereas the Zambezi is part of the plain highland, the other three test sites are located in terrain with higher relief energy.

The first test site is located in the Zambezi region. The high annual precipitation allows for savanna woodland as well as grassland (Hüser *et al*. 2001). Cropland can be found especially along the major roads and in proximity to settlements (Mendelsohn *et al*. 2009). The second test site contains the southwestern part of the Waterberg. Here a mosaic of vegetation and rocks form the plateau (Hüser *et al*. 2001). The surroundings are partially used for farming (Mendelsohn *et al*. 2009). The third test site lies on the foothills of the Great Escarpment. Its land cover is substantially affected by the arid climate (Jacobson *et al*. 1995). Vegetation can almost only be found along the banks of the ephemeral and endorheic river Tsondab and its inflows (Jacobson *et al*. 1995). The Brandberg Mountain area forms the last test site. Even though the climate is arid (Nordenstam 1974), plants can grow thanks to the rainfall-increasing impact of the relief (Hüser *et al*. 2001). The ephemeral river Ugab (Eckardt *et al*. 2001) runs through the north of the tile suggesting the presence of denser riverine vegetation.

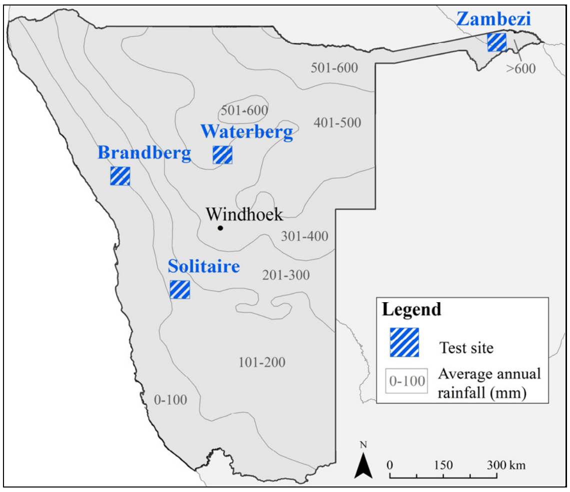

***Figure 1**: Average annual rainfall and locations of the four test sites.*

Land Cover Products

The comparison included five freely available low to medium resolution products (Table 1). The global dataset *DISCover* classified according to the IGBP (International Geosphere Biosphere Programme) scheme is based on monthly maximum Normalised Difference Vegetation Index (NDVI) composites of the months April 1992 to March 1993 derived from the NOAA-AVHRR (National Oceanic and Atmospheric Administration – Advanced Very High-Resolution Radiometer) satellite sensor scheme (Hansen & Reed 2000). These served as input into an unsupervised cluster classification. The *MODIS* (Moderate Resolution Imaging Spectroradiometer) *MCD12Q1* Version 6 product of the year 2016 was

***Table 1:** The land cover products and their spatial resolution. Sources: Friedl & Sulla-Menashe (2018), Hansen & Reed (2000), Ramoino et al. (2018), Santoro et al. (2017), Servir Global (2015).*

Product	Sensor	Spatial Resolution	Period of Data Acquisition	Classification Scheme	Spatial Coverage	Overall Accuracy *	Group
DISCover	NOAA AVHRR	1000 m	April 1992 - March 1993	IGBP	Global	59.4%	Low resolution
MCD12Q1 V006	MODIS	500 m	2016	IGBP	Global	-	
CCI-LC 2015	MERIS FR & RR, SPOT-VGT, AVHRR & PROBA-V	300 m	2015	FAO LCCS	Global	71.5%	
Namibian Land Cover 2010 Scheme II	Landsat 5 TM	30 m	2009 - 2011	Modified LC categories of the IPCC	Namibia	76.9%	Medium resolution
S2 Prototype LC 20 m Map of Africa 2016	Sentinel 2	20 m	December 2015 - December 2016	Own classification scheme	Africa	65.0%	

**Overall accuracy computed by the product developers*

chosen as a second product, also containing classes of the IGBP scheme. The product was developed using a supervised classification algorithm of MODIS reflectance data (Friedl & Sulla-Menashe 2018). As a third global medium-resolution product the ESA *CCI-LC* (*Climate Change Initiative Land Cover*) of the year 2015 was used. The product is based on the time series of MERIS (Medium Resolution Imaging Spectrometer) Full Resolution (FR) and Reduced Resolution (RR), but it is supplemented by images of SPOT-VGT (Satellite Pour l'Observation de la Terre - VEGETATION), AVHRR and PROBA-V (Project for On-Board Autonomy - Vegetation) allowing for mapping and incorporation of land cover changes (Santoro *et al*. 2017). The legend was developed applying the Land Cover Classification Scheme (LCCS) of the United Nations (UN) Food and Agriculture Organization (FAO). This was supposed to facilitate comparisons with other global land cover products.

The medium-resolution and national dataset *Namibia Land Cover 2010 Scheme II* (NLC 2010) served for a more detailed comparison. It was generated using images derived from the sensor Landsat 5 TM (Thematic Mapper) of the years 2006, 2010 and 2011 as inputs for a supervised classification. A country-specific legend with 13 classes was created, which is based on the LC categories of the Intergovernmental Panel on Climate Change (IPCC) (Servir Global 2015). The *S2 LC Africa* product was developed applying the classification algorithms Machine Learning and Random Forest to data of the sensor Sentinel-2A for the period December 2015 until December 2016. The two resulting maps were then combined allowing the selection of best land cover representations. The initial 22 classes of the global *CCI-LC* map were reduced to the ten most relevant land cover classes for the African continent (Ramoino *et al*. 2018).

Legend Harmonisation

A quantitative and qualitative comparison was used to show differences between the land cover products. A key challenge before product comparison was the harmonisation of the different legends, as the number of classes as well as their definitions varied substantially. By assigning a common legend to all datasets the classifications became comparable. The developed legend (Table 2) is based on the *S2 LC Africa* product due to the lower number of classes, the absence of mixed classes and the broader formulation of classes.

Comparison of Land Cover Products

The reference products were compared to the *S2 LC Africa* classification in respect to common features and classification differences using the geographical information system ArcMap 10.4 of the company ESRI. So-called agreement maps (Figure 4) were produced to visualise areas of uncertainty or mismatch as well as areas of thematic consistency in the map outputs, allowing conclusions on product accuracy. Prior to the comparison, the spatial

Table 2: *The classes of the common legend and the assignment of the respective classes per product.*

Value	Class	Description	DISCover & MCD12Q1	CCI-LC 2015	NLC 2010
0	Unclassified		100	0	0
1	Woodland	Opened to closed woodlands with a minimum surface coverage of 10%	1, 2, 3, 4, 5, 8, 9	60, 62	1, 2
2	Shrubland	Opened to closed shrubs and bushes; proportion of trees must not exceed the proportion of the shrubs	6, 7, 14	11, 12, 40, 100, 110, 120, 122	4
3	Grassland	Dominance of grasses; the proportion of woody plants must be negligible	10	130	3, 5
4	Cropland	Comprising cultivated as well as uncultivated, irrigated as well as unwatered fields	12	10, 20, 30	6
5	Wetland	Regularly flooded areas which can be covered by grasses, shrubs and trees	11	180	7
6	Sparse vegetation, lichens, mosses	Sparsely vegetated areas, lichens or mosses	*	150, 153	*
7	Bare areas	Areas without vegetation or almost no vegetation such as rocks, barren soil, dunes, desert, salt pans and streets	16	200, 201, 202	10, 11, 12, 13
8	Built up areas	Artificial surfaces, settlements and industrial areas; excluding streets	13	190	9
9	Permanent snow and/or ice	Areas that are covered with snow and/or ice all-season	15	*	*
10	Water bodies	Areas that are covered with water all-season	17	210	8

**Class does not exist in the classification*

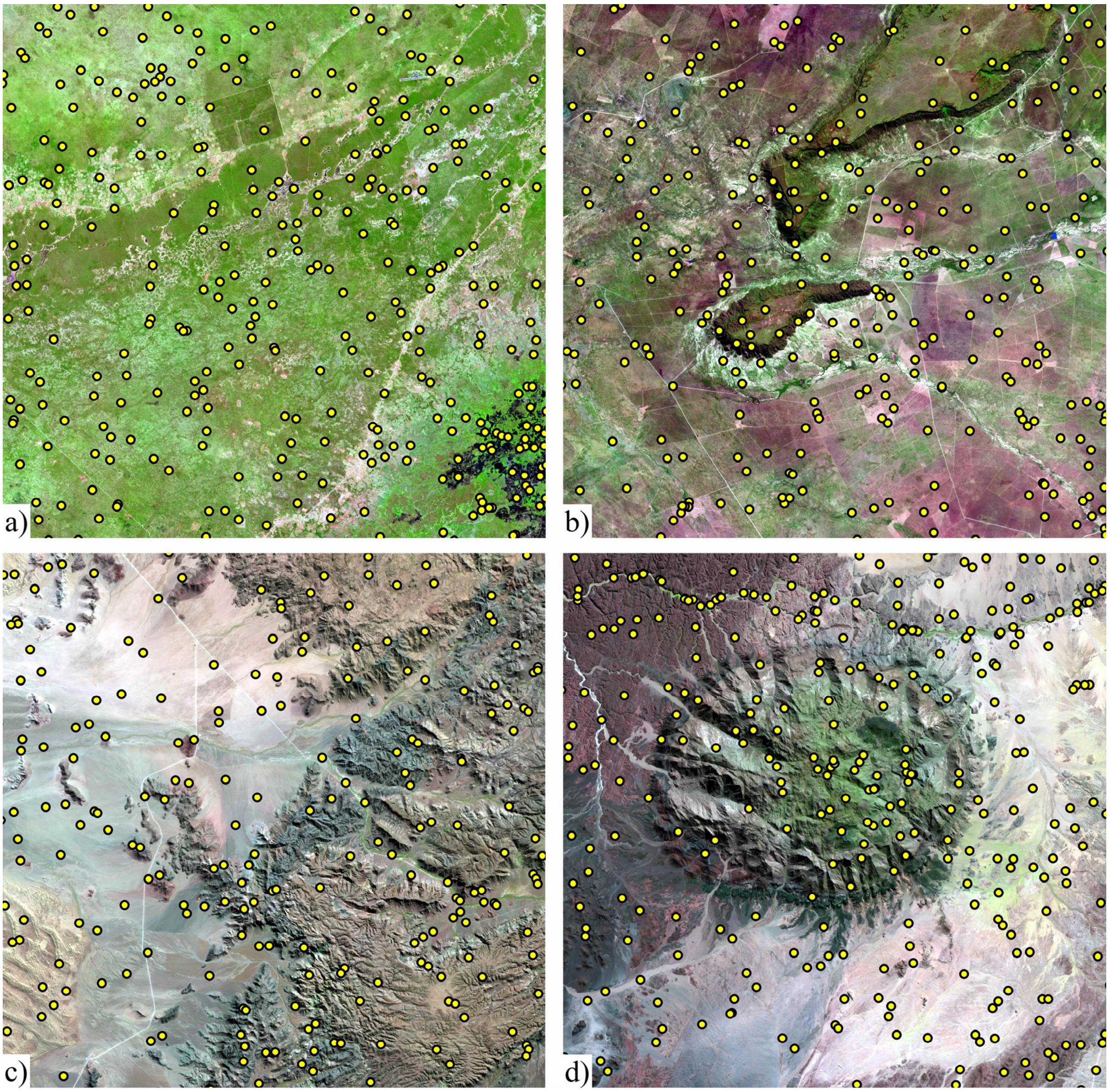

***Figure 2**: False-colour images (SWIR1 – NIR – Red) of the test sites (a) Zambezi, (b) Waterberg, (c) Solitaire and (d) Brandberg showing the location of the reference data.*

resolution of the reference maps was resampled to the higher resolution prototype dataset.

Accuracy Assessment

The majority of the datasets analysed in this paper include their own accuracy assessment (Table 1). However, comparability is limited as products were derived using different methodologies and reference data. For that reason, a common accuracy assessment was performed to evaluate the land cover datasets. The accuracy assessment was carried out by means of an error or confusion matrix which is a cross tabulation of classification results against reference data. An error matrix allows for statistical conclusions on the proportion of correctly classified pixels and the dependency of misclassifications on other classes (Lange 2002). The derived classification accuracy parameters included the overall accuracy (OA) as the percentage of pixels classified correctly, the producer's accuracy (PA) as the percentage of correctly classified reference data and the user's accuracy (UA) as the percentage of correctly classified map pixels (Lange 2002). Moreover, the kappa coefficient was calculated which indicates how good the classification results compare to reference data. Kappa coefficient values range between 0 (no agreement between the classification results and the reference data) and 1 (total agreement between the classification results and the reference data) (Congalton & Green 2009).

The reference data were generated applying a stratified sampling methodology (ground truthing).

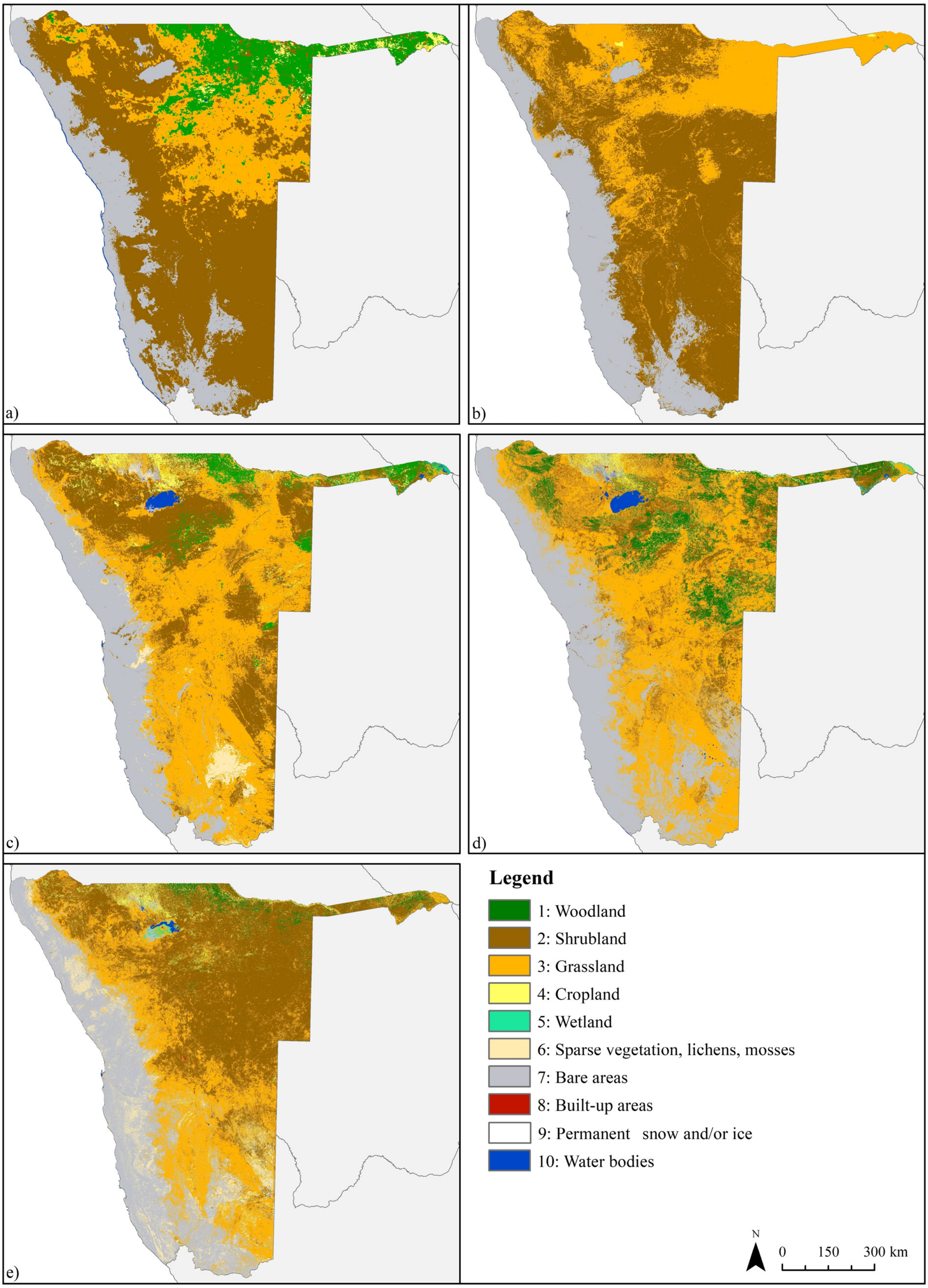

***Figure 3**: Reclassified land cover products DISCover, 1993 (a), MODIS/Terra & Aqua Combined Land Cover Type Global 500 m SIN Grid (MCD12Q1 2016) (b), Climate Change Initiative Land Cover (CCI-LC 2015) (c), Namibia Land Cover 2010 Scheme II (NLC 2010) (d), Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016 (S2 LC Africa) (e) with legends harmonized to the Sentinel 2 product.*

According to Congalton (1991) the minimum number of reference points for each land cover class should be 50. Classes of greater extent require between 75 and 100 samples. In this study the maximum number of samples was limited to 338 for Zambezi, 296 for Waterberg, 228 for Solitaire and 334 for Brandberg (Figure 2). The number depended on the test site's diversity and land cover heterogeneity. The sampling points were classified based on visual image interpretation of recent high-resolution World Imagery Basemap of ArcGIS, SPOT imagery with a spatial resolution of 5 m acquired in 2010 as well as Aerial Orthophotos acquired in 2009 with a 1 m spatial resolution covering the northern communal areas. The multi-temporal approach was necessary as different time stamps of the investigated land cover products have effect on land cover and land cover changes over time.

RESULTS

Comparison of freely available Land Cover Products

Significant differences in the distribution of land cover classes can be seen countrywide, but vary depending on the product. Areas in the northeast with small-scale mosaics of land cover, where woodlands are mixed with shrubs, grass and cropland (Hüser *et al.* 2001), represented a major challenge for

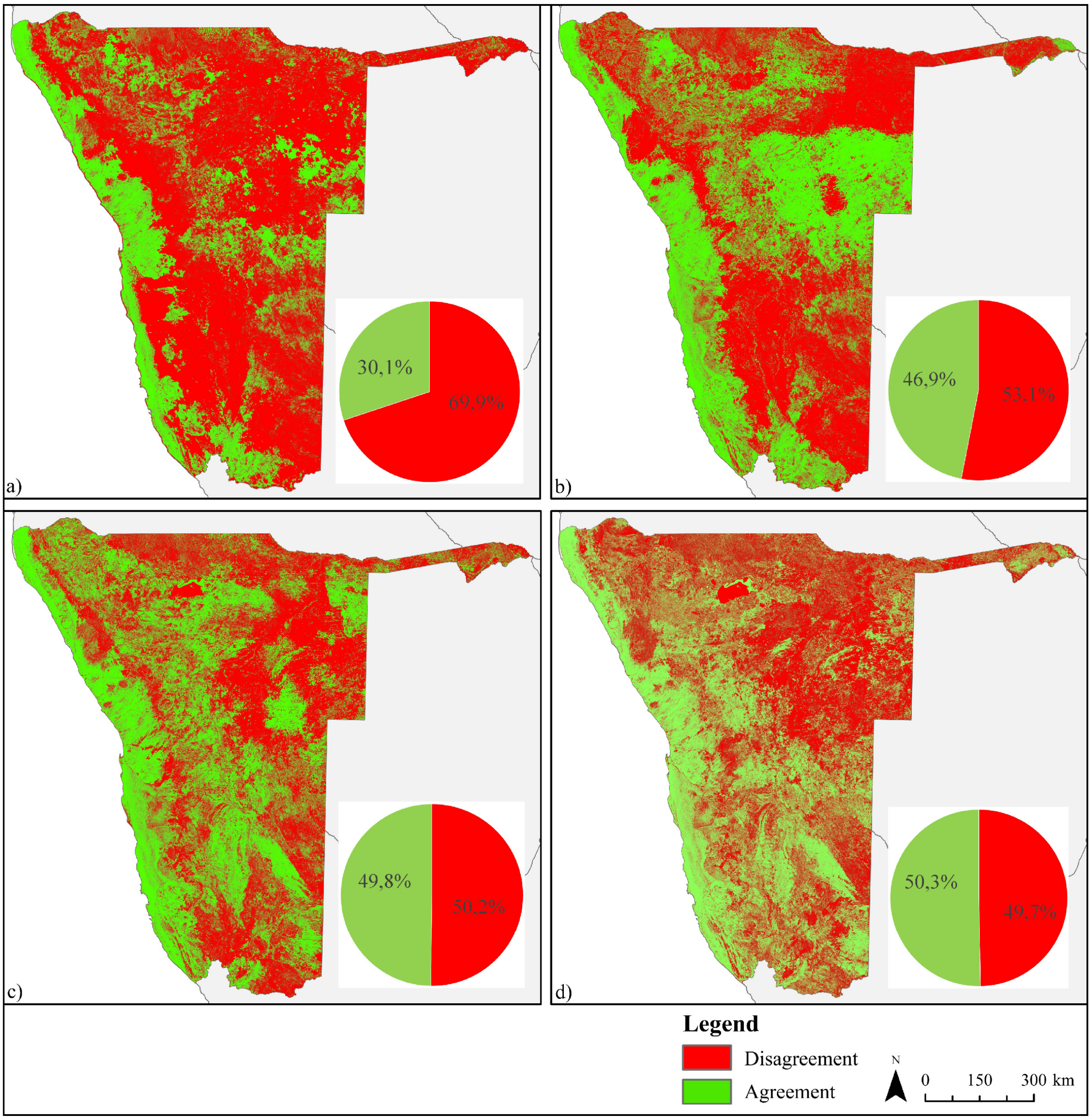

***Figure 4**: Spatial agreement and disagreement among the datasets Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016 (S2 LC Africa) and (a) DISCover; (b) MODIS/Terra & Aqua Combined Land Cover Type Global 500 m SIN Grid (MCD12Q1); (c) Climate Change Initiative Land Cover (CCI-LC); (d) Namibia Land Cover 2010 Scheme II (NLC 2010).*

consistent mapping. However, also large areas with predominantly homogenous land cover types show patterns of disagreement. In the southern area, where shrubland is interspersed with grassland (Mendelsohn *et al*. 2009), the disagreement is largely due to the under-representation of grassland in the *DISCover* and *MCD12Q1* products (Figure 3).

Figure 4 shows the spatial agreement and disagreement between the *S2 LC Africa* product and the four chosen reference products. All four maps show large areas of agreement along the coastline of Namibia due to the extensive dune belt and the large-scale gravel plains of the Namib desert (Leser 1982). Irregular patterns of disagreement increase further inland (i.e. in the transition zone between the Great

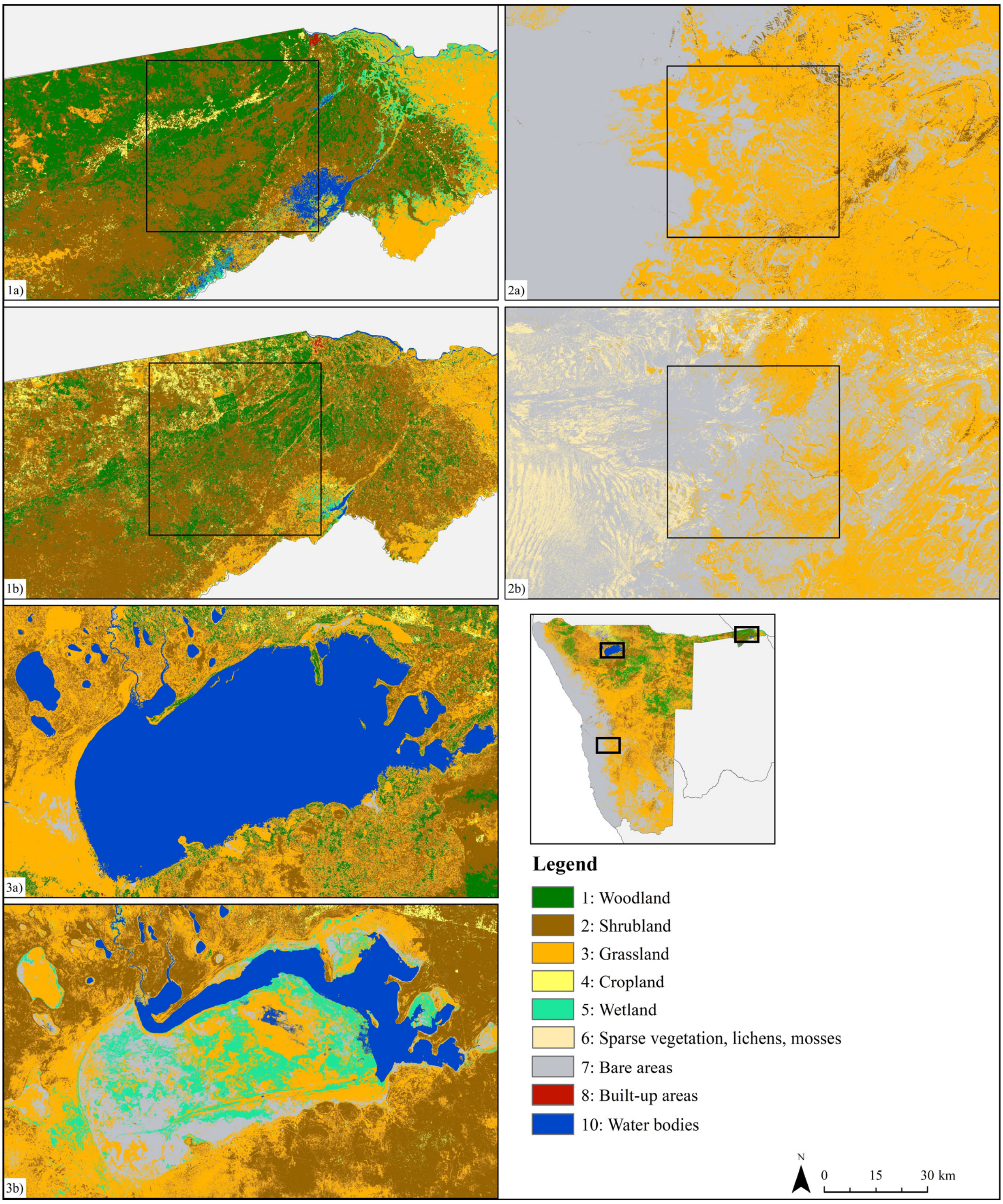

Figure 5: *(1) The Zambezi region, (2) the Solitaire region and (3) the Etosha Pan classified by (a) the Namibia Land Cover 2010 Scheme II (NLC 2010) and (b) the Sentinel 2 Prototype Land Cover 20 m Map of Africa 2016 (S2 LC Africa. Locations are visible in the overview map.*

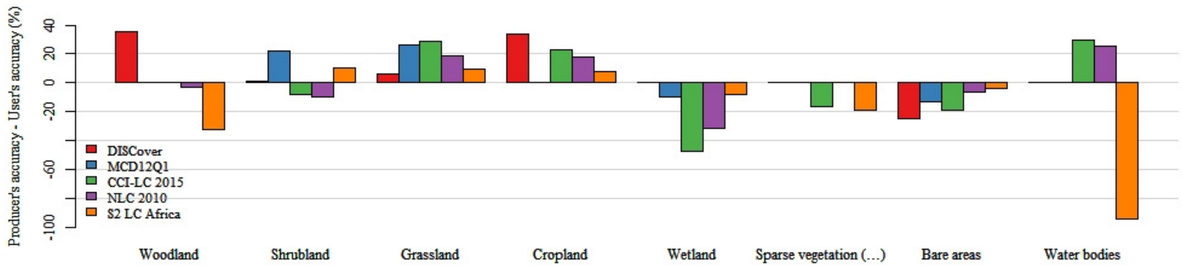

***Figure 6**: Difference between the producer's and the user's accuracy.*

Escarpment and the coast or towards the central-eastern regions, Kalahari).

The highest level of agreement is visible when comparing the *NLC 2010* and the *S2 LC Africa* product. The comparison with the *DISCover* map shows the highest disagreement. The increase of agreement thus correlates with the increase of sensor resolution (Table 1), suggesting higher thematic accuracies of these products. The disagreement amounting to 49.7% of the total area in the agreement map of *S2 LC Africa* and *NLC 2010* (Figure 4c) tends to slightly negatively correlate with the rainfall gradient. Therefore, it is opposed to vegetation density and height. As already mentioned, the largest connected agreement area covers the coast where land cover varies slightly. This leads to a relatively high percentage of qualitative correlation (35%) of bare areas. The grassland class shows the second highest qualitative agreement of 27%.

The map extracts (Figure 5) compare the *NLC 2010* product with the *S2 LC Africa* product for selected sites. The Etosha Pan is a salt pan which is irregularly flooded in the rainy season but dry during the winter (Namibia National Commission for UNESCO 2016). Due to seasonally changing land cover patterns, correct mapping of the salt pan is definitely a challenge. The *NLC 2010* product classified it as a permanent water body. The *S2 LC Africa* product shows a mosaic of barren, vegetated and flooded areas. The test sites Zambezi and Solitaire also show significant differences such as an under-representation of sparse vegetation in the *NLC 2010* product extract for 'Solitaire' and a seemingly more detailed representation of the classes woodland, shrubland and cropland in the *S2 LC Africa* product extract in the Zambezi region.

Accuracy Assessment

The accuracy varies depending on land cover class and spatial resolution (Table 3). Bare areas were classified most precisely. The class sparse vegetation, lichens, mosses shows complete disagreement due to the absence of corresponding classes in the original legends. The error matrix reveals a clear trend to higher accuracy values as the spatial resolution increases. Therefore, the *S2 LC Africa* product has the highest OA and the highest kappa coefficient of all freely available products. None of the analysed classifications is satisfactory according to Anderson *et al*. (1976) or Fitzgerald & Lees (1994) who defined a minimum accuracy of 85% and 70%, respectively. Considering the kappa coefficient values, only the prototype classification reaches a medium agreement (kappa coefficient ≥0.4) according to Congalton & Green (2009).

To evaluate the balance between the producer's and the user's accuracy, the differences between these two measurements were calculated (Figure 6). The

***Table 3:** Accuracy assessment showing the overall accuracy (OA, %), user's accuracy (UA, %) and producer's accuracy (PA, %) and the kappa coefficient of the freely available land cover products for the four test sites (summed up).*

	DISCover		MCD12Q1		CCI-LC 2015		NLC 2010		S2 LC Africa	
	UA	PA	UA	PA	UA	PA	UA	PA	UA	PA
1: Woodland	35.7	71.1	0	0	40.3	40.6	59.1	56.1	76.0	43.9
2: Shrubland	17.6	19.1	36.2	58.6	37.2	29.2	51.9	42.6	57.4	67.7
3: Grassland	12.4	18.7	12.3	38.3	11.4	40.2	7.7	26.2	10.7	20.6
4: Cropland	5.9	40.0	0	0	16.7	40.0	22.2	40.0	2.4	10.0
5: Wetland	0	0	23.1	13.0	60.0	13.0	40.0	8.7	21.4	13.0
6: Sparse vegetation, lichens, mosses	0	0	0	0	22.0	5.8	0	0	41.7	22.7
7: Bare areas	76.3	51.7	72.8	59.4	75.9	56.8	68.2	61.5	79.5	76.0
10: Water bodies	0	0	0	0	39.3	68.8	31.0	56.3	100.0	6.3
OA	34.5		38.5		38.1		43.3		54.4	
Kappa	0.18		0.21		0.24		0.29		0.41	

Table 4: *Accuracy assessment showing the overall accuracy (OA, %) and the kappa coefficient of the freely available land cover products for the four test sites.*

		DISCover	MCD12Q1	CCI-LC 2015	NLC 2010	S2 LC Africa
Zambezi	OA	33.4	13.9	59.6	44.7	45.3
	Kappa	-	-0.9	23.6	23.1	24.7
Waterberg	OA	18.9	53.0	31.4	39.2	53.0
	Kappa	7.6	2.2	8.1	23.8	21.2
Solitaire	OA	22.8	27.2	20.6	21.5	51.3
	Kappa	6.5	9.3	7.0	5.8	15.4
Brandberg	OA	53.9	59.9	59.6	59.9	67.7
	Kappa	17.5	19.4	23.6	11.4	41.5

balance varies strongly among the different classes and products. *S2 LC Africa* shows the highest imbalance due to the strong bias towards the user's accuracy in class Water bodies. The product *CCI-LC 2015* shows the second highest imbalance. The results of *DISCover* and *MCD12Q1* are more concerted but difficult to compare due to the presence of zero values. The classes shrubland, sparse vegetation, lichens, mosses and bare areas are the least biased in all land cover products.

The achieved accuracies vary considerably. Not only for the land cover products but also for the four chosen test sites (Table 4). All products achieve the highest accuracy for the test site Brandberg. One reason might be the more homogeneous land cover which is predominately unvegetated and bare and can therefore be mapped with little confusion. In contrast, the test site Solitaire was classified with almost exclusively low values mostly due to confusions in the classes shrubland, grassland, sparse vegetation, lichens, mosses and bare areas. Terrain variability, which is more homogeneous within the Zambezi test site compared to the mixed terrain of the other three test sites, does not seem to influence classification accuracy.

DISCUSSION

The applied methodology is one possible way to compare and validate land cover classifications. However, it should be considered that inherent dataset characteristics and personal assumptions might have induced some bias in the results. The re-classification of the reference products could have modified the classification results to some extent. Even though it was conducted with care, a perfect re-coding of some classes was challenging because of missing or insufficient class descriptions. The biggest challenge was the re-classification of mosaic classes. These contain several land cover types, which are subject to regional differences in vegetation composition. Furthermore, it should be noted that, although assumed to be correct, the ground truth data is easily subject to misinterpretation. According to Congalton & Green (2009) up to 30% of the differences between the reference data and the classification results are likely to be the result of subjective interpretation.

Apart from procedural issues, natural processes are likely to have caused some disagreement. Landscape units or land cover itself can easily be influenced through seasonal and inter-annual changes. The transition from dry to rainy season leads to changes in phenology every year (Hassler *et al*. 2010). Due to the significant time difference in the data collection of up to 26 years, it is highly probable that real land cover changes such as desertification (Klimm *et al*. 1994, Seely & Klintenberg 2011), bush encroachment (Mendelsohn & Obeid 2005) or urbanisation (Röder *et al*. 2015) took place and led to disagreements when comparing the reference datasets with the prototype classification. Timely differences and the lack of high-resolution reference imagery definitely had an effect on the evaluation of the older *DISCover* land cover product based on imagery of the years 1992 and 1993. For time reasons the study did not include historical imagery which can be accessed in Google Earth Pro. The other products were derived from imagery of almost the same period in time (see section on land cover products).

Consequently, most of the differences can be assumed to be the result of misclassification. This is the case in the north due to the overestimation of grassland in the *CCI-LC 2015* and *NLC 2010* products. Apart from a few exceptions, extensive grassland can be located in the transition area from the central highland to the Namib desert (Hüser *et al*. 2001), whereas in the north, grassland only covers small areas near rivers or is mixed with other types of land cover (Mendelsohn *et al*. 2009). Most of the country, however, is dominated by shrubland of different densities (Hüser *et al*. 2001). The S2 prototype classification displays the distribution of grassland more accurately, yet slightly

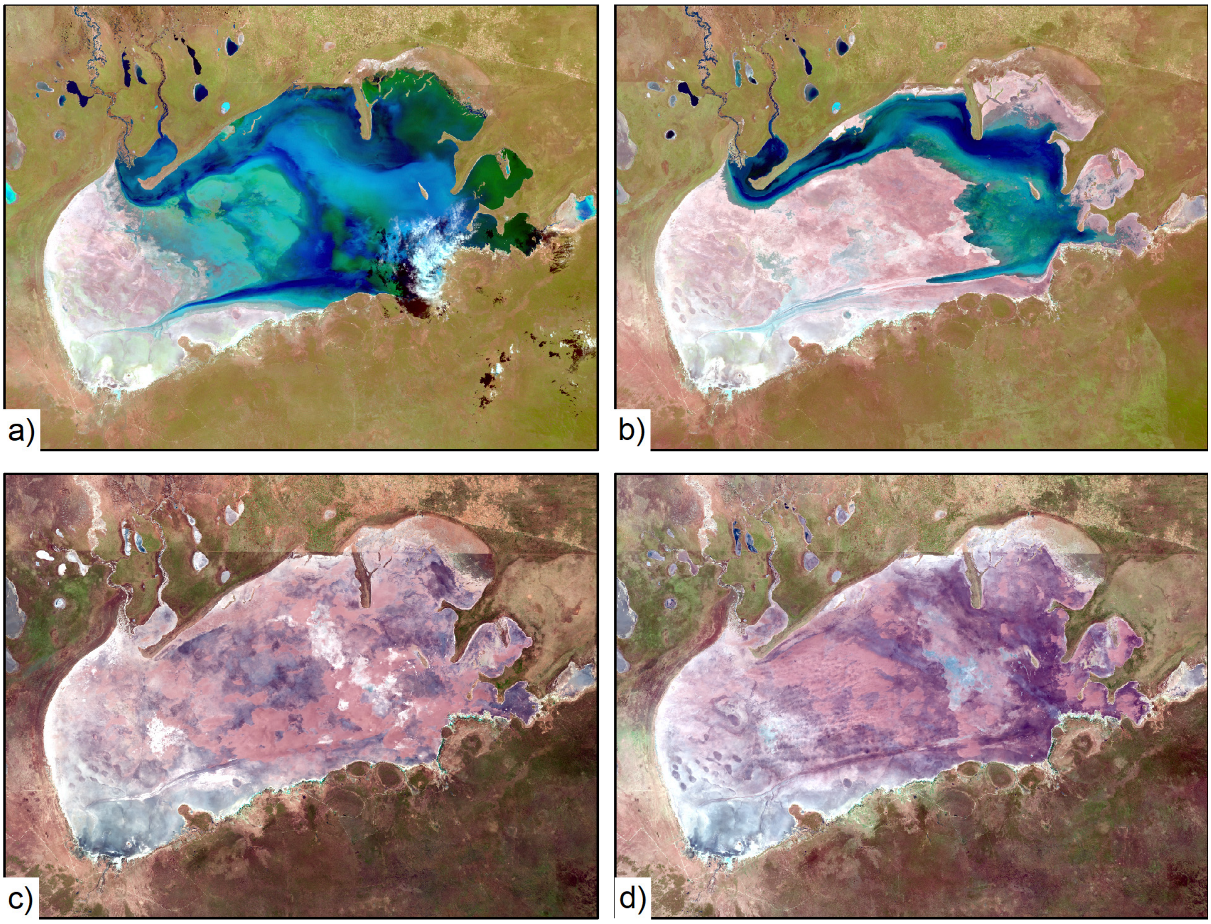

Figure 7: *Images of Landsat-5 and Landsat-8 as false natural colour composites showing the desiccation of the Etosha pan in (a) May 2009; (b) May 2010; (c) June 2015; (d) May 2016. Source: USGS (2018).*

overestimating it in parts of the country. Varying results can rather be attributed to the presence of different land cover types, particularly in areas of land cover mosaics which can be challenging for consistent mapping, especially when the heterogeneity leads to the generation of mixed pixels. In general, this issue is independent from the spatial resolution of the satellite sensor. However, low-resolution sensors produce higher amounts of mixed pixels (Fisher & Pathirana 1990).

The map extract of the Etosha pan (Figure 5) suggests that small-scale mosaics were classified more accurately in the *S2 LC Africa* product dataset. Although the years of the data collection (2009-2011) for the *NLC 2010* map were extraordinarily high in precipitation (Earth Observatory 2018), displaying the whole area as a permanent water body is considered critically. Firstly, satellite images prove that the salt pan dried out in the dry season of the years considered (Figure 7). Secondly, images of the dry season were preferred according to the product description. Consequently, a classification as a mosaic of barren, vegetated and flooded areas, as described by the Namibia National Commission for UNESCO (2016), is believed to be more realistic. This finding implies that the higher resolution prototype map provides more precise information on the actual land cover than the lower resolution reference datasets. This assumption is confirmed by the accuracy assessment, however, some of its per class accuracies are still on a low level. This finding implies that other factors such as spatial coverage, tools and classification procedures influence the accuracy of land cover products.

CONCLUSION

The results of the study suggest that the *S2 LC Africa* product constitutes a major improvement for land cover mapping of Namibia. It is more detailed and precise in terms of quantitative and qualitative representation of land cover than the low and medium-resolution reference datasets. However, the accuracies per class are still too low to meet the user requirements of a good qualitative and reliable land cover map which can be used as a basis for environmental analysis. Consequently, further improvements should be made to satisfy all user needs. Finally, it should be noted that the results do

not represent a complete accuracy assessment of the analysed products since these are limited to the test sites. The objective was rather to provide information on the possible strengths and weaknesses of the datasets, and to contribute to the validation of the *S2 LC Africa* product. Hence further examination and validation is recommended. These should include reference data for the whole country to ensure meaningful results.

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